Theoretical Model of an Acoustic Wave Liquid Conductivity Sensor

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Recent experiments have shown that thickness shear mode (TSM) bulk acoustic wave (BAW) resonators with novel electrode geometries are very sensitive to the liquid electrical property changes (conductivity and permittivity) and can be used as a sensitive detector of electrical property changes in liquids [1]. Experiments in air showed that these resonators could not be excited, however when exposed to a liquid with finite conductivity, efficient excitation of the resonator occurred. This suggested that the liquid in contact with the resonator formed a lossy electrode on the sensing surface. Since the frequency response of this sensor cannot be explained using available circuit models [2], it is the purpose of this paper to develop an equivalent circuit capable of explaining the response of this sensor.

A schematic cross sectional diagram of a TSM resonator with a very small electrode overlap area is shown in Fig. 1, along with the proposed equivalent circuit model. The electrode on the sensing surface consists of a small metallic electrode and the conductive fluid which can be defined as a lossy liquid electrode. R_0 and C_3 are related to the liquid conductivity and permittivity respectively. R, C_1 and L arise from the piezoelectric effect of the quartz plate and C_0 represents the static capacitance in the partial metalized area across the quartz plate. C_2 is the static capacitance formed by the small electrode overlap area. R, C_1, L and C_0 form a resonator, which can be excited through the lossy electrode characterized by R_0 and C_3.

In the present study, resonators with different electrode geometries were fabricated from commercial AT-cut 5 MHz resonators, where the sensing electrode in contact with the liquid was much smaller than the reference electrode. The resonators were exposed to NaCl solutions with different concentrations and the impedance was measured with a network analyzer. A program in Matlab was developed to fit the measured impedance with the proposed model.

Fig.2 shows the experimental and simulation result for the resonator with one of the novel electrode geometries. The solid line represents the measured impedance, the dashed line represents the impedance calculated from the present model, and the dotted line represents the impedance from the model in [2]. The NaCl concentrations are 0% and 0.037% (weight percent). From Fig.2, it can be seen that the present model agrees well with the measured impedance, while the model in [2] shows significant derivations. Similar results have been obtained for other NaCl concentrations and resonators with other novel electrode geometries. Circuit parameters in the present model as a function of the NaCl concentration have been determined, which may provide a guideline for the electrode design of the future BAW sensors.

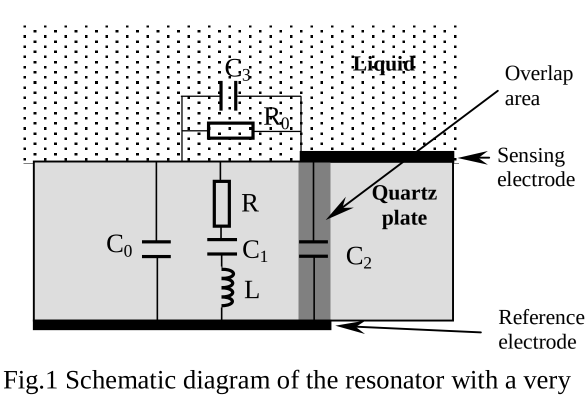

Fig.1 Schematic diagram of the resonator with a very small electrode overlap area and the proposed equivalent circuit model for the resonator operating in a conductive liquid.

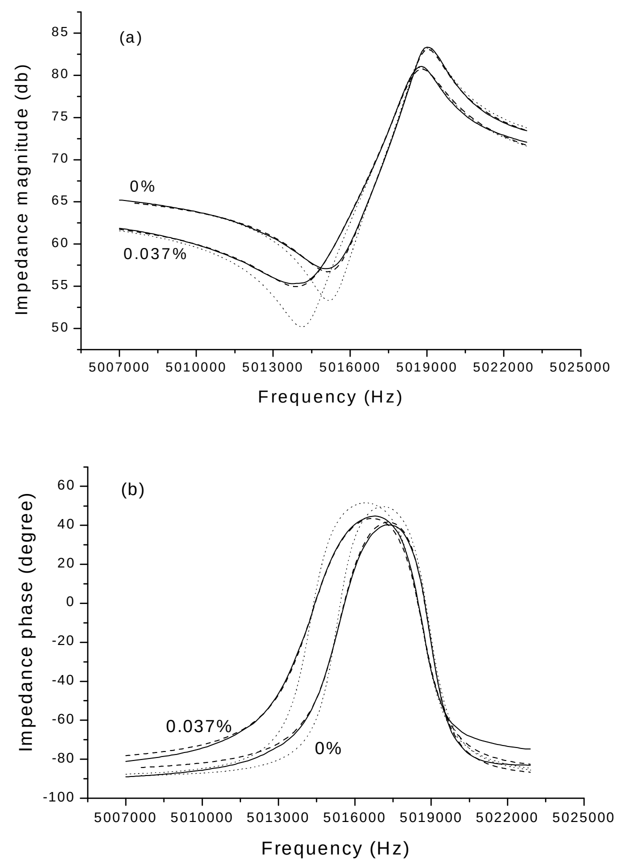

Fig.2 Comparison of the measured impedance (solid line), the impedance calculated from the present model (dashed line) and from the previous model (dotted line) for NaCl concentration of 0% and 0.037%.
(a) The impedance magnitude; (b) The impedance phase

REFERENCES
[1] C. Zhang and J. F. Vetelino, IEEE Trans. on UFFC, May 2001 (in press).
[2] Y. Lee, D. Everhart and F. Josse, IEEE Freq. Cont. Symp. Proc., p. 577-585, 1996.

Fig.1 Measured frequency shifts of 5 MHz TSM resonators with different electrode geometries as a function of 2-propanol concentration in solution. d_{cr} and d_{or} are the inner diameter of the closed and open ring electrode geometry.